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(54) Title: INDUCTION MOTOR PROPULSION SYSTEM FOR POWERING AND STEERING VEHICLES.
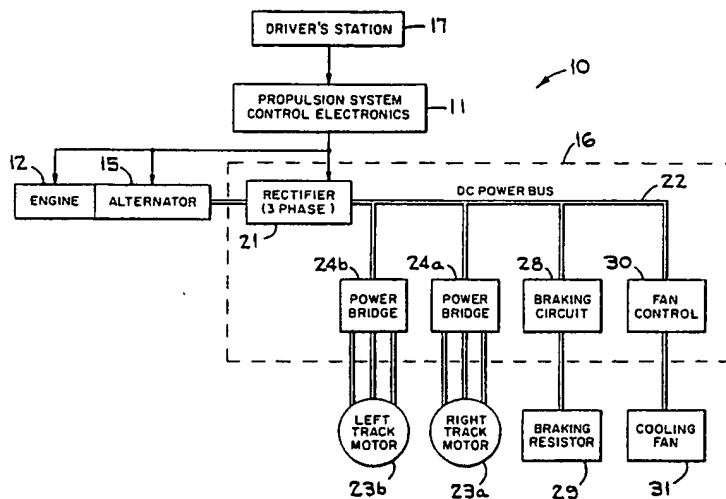
(57) Abstract

A propulsion system for using a pair of electric induction motors (23a, 23b) to power a pair of vehicle drive wheels. The motors are driven by pulses of electric current from a common dc bus (22). The inductance of stator windings cause electric current to power the motors during the time between pulses so power from the dc bus is low. When a vehicle is making a tight turn, an inside motor provides an electric current to the dc bus to supply additional power to an outside motor. Speed and steering signals operate the electric motors and control speed of an engine (12) and an alternator (15) which supply power to the dc bus.

INDUCTION MOTOR PROPULSION SYSTEM FOR POWERING AND
STEERING VEHICLES

BACKGROUND OF THE INVENTION

This invention pertains to a system for
5 powering and steering vehicles, and more particularly,
to a system for using electrical propulsion to power,
steer and brake heavy vehicles for precise control at
all vehicle speeds.

The present invention is useful with tracked
10 and other power vehicles to provide higher agility in
the form of greater acceleration, higher speeds on
slopes, better control over forward speed in turns,
better fuel efficiency and a flexible drive train
arrangement. Electric drives in combat vehicles allow
15 major components, such as the engine, to be placed
anywhere in the vehicle without mechanical connections
between the engine and the drive wheels or gears, and
allow weight to be reduced. The same power used for
the propulsion system can also be used to charge the
20 weapon and armor system storage devices. The
electrical energy storage can provide extended silent
watch, silent-run ability and emergency get-home
capability in the event of damage to the vehicle
engine system.

25 ## SUMMARY OF THE INVENTION

The present invention comprises circuitry for
powering and steering vehicles by providing individual
controlled power to a pair of vehicle tracks in
response to a speed command and a steering command.

30 A first electric motor provides a controlled
amount of power and speed to a first vehicle track in
response to the combination of a speed command signal,
a steering command signal and a first track speed
signal. A second electric motor provides a controlled

amount of power and speed to a second vehicle track in
response to the combination of the speed command
signal, the steering command signal and a second track
speed signal. When a track speed is greater than the
5 combination of the steering command signal and the
speed command signal, the electric motor provides
braking of the corresponding vehicle track by
returning power to a common dc bus. The same
circuitry can be used with nontracked vehicles by
10 providing power to individual vehicle wheels. (The
sum of electric motor speed errors control operation
of an engine which drives an alternator that provides
power to the common dc bus.)

                    BRIEF DESCRIPTION OF THE DRAWINGS
15   Figure 1 is a block diagram of an
electric-drive vehicle propulsion system of the
present invention having totally electrical
regenerative steering and braking.
            Figure 2 is a block diagram of an electric
20 circuit for controlling engine speed motor power
output, alternator output voltage, vehicle braking and
for powering and steering a first side of a vehicle.
Another electric circuit containing a duplicate of a
portion of Figure 2 provides power and steering for a
25 second side of the vehicle.
            Figures 3A, 3B comprise an electronic circuit
showing details of a portion of Figure 2.
            Figures 4A, 4B, 5A, 5B are electronic
circuits each showing details of other portions of the
30 circuit of Figure 2.
            Figure 6 shows details of circuits which
provide power to drive the electric motors and to
power the vehicle.
            Figure 7 illustrates voltage waveforms used
35 in controlling electric current applied to the

electric motors which power the vehicle.

Figure 8 is an enlarged view of a portion of Figure 6 showing operation of the circuit used to drive one of the electric motors.

5   DESCRIPTION OF THE PREFERRED EMBODIMENT

An induction motor propulsion system 10 of Figure 1 includes an electronic control 11 which provides control signals to an engine 12, an alternator 15 and a power electronics assembly 16 in
10 response to signals from a driver's station 17. Three-phase ac power generated by alternator 15 is converted to dc power by a rectifier 21, coupled to a dc power bus 22 and used to power a pair of track motors 23a, 23b under the control of a corresponding
15 pair of power bridges 24a, 24b. A braking circuit 28 selectively couples bus 22 to a braking resistor 29 to providing electronic braking for a vehicle (not shown) in which system 10 can be used. A fan control 30 selectively couples bus 22 to an engine cooling fan
20 31. When the vehicle is turning sharply the inside track motor 23a or 23b acts as a generator and returns power to bus 22 for use by the outside track motor. This provides regenerative steering of the vehicle for effective control without the need for mechanical
25 brakes or clutches. When driver's station 17 asks for a slower vehicle speed, motors 23a, 23b both return power to bus 22 thereby causing braking circuit 28 to dump power from bus 22 into braking resistor 29 and effectively braking motors 23a, 23b. System 10 is
30 able to develop 1000 hp for the two 500 hp motors 23a, 23b and to propel a 50 ton vehicle. The electronic control 11 receives forward command, steer command, and forward - reverse command signals from the driver's station 17 (Fig. 1). In addition, motor
35 speed and direction signals, engine throttle position

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and dc bus voltage signals are received.

An induction motor propulsion control system 39 of Figure 2 includes a speed control P1 and a steering control P2 to provide control signals for 5 powering and steering a vehicle. A switch 42 having a forward contact Fr and a reverse contact Rv provides signals for operating a vehicle in forward and reverse directions. A dc reference voltage on an input terminal T1 and a vehicle speed voltage on an input 10 terminal T2 are combined in an adder A1 to provide a voltage to speed control P1. The setting of speed control P1 provides a speed command signal which an adder A2 combines with the vehicle speed voltage on terminal T2 to provide a difference signal to an input 15 lead 43 of a circuit 44. This signal on input lead 43 represents the difference between the actual vehicle speed and the desired vehicle speed and is used to increase or decrease the speed of motors 23a, 23b (Fig. 1) until the actual vehicle speed is equal to 20 the desired speed. A speed sensor 45 (Fig. 2) having an associated rotating gear 48 develops a vehicle speed signal proportional to the speed of a track sprocket 49 and of a vehicle track 50. A terminal T2a from speed sensor 45 is connected to terminal T2 to 25 provide the vehicle speed voltage for adder A2.

The difference signal on input lead 43 is also used to set engine speed. Circuit 44 produces a voltage that is proportional to speed error. Adder A3 sums desired engine idle speed with vehicle speed. 30 Circuit 54 produces a desired engine speed that is the output of adder A3 or the output of circuit 44 whichever is greater. An engine speed circuit 57 provides an actual engine speed signal to adder A4 which develops a difference speed signal which is 35 amplified by an amplifier 61 and applied to a circuit

64. A throttle position potentiometer P3 provides a throttle position signal which is determined by the position of an engine throttle 62 of engine 12. The throttle position signal is amplified by circuits 63

5 and applied to circuit 64 also. The output of circuit 64 is amplified by A5. The output of A5 is coupled to a pulse width modulator (PWM) 69 which develops a voltage which causes a small servo motor 70 to position throttle 62 for desired engine speed. The

10 rotation of motor 70 is opposed by a spring 74 connected to throttle 62.

The input signal to PWM 69 (Fig. 2) is also coupled through a circuit 75 and combined with the signal from amplifier 44 by an adder A6 to produce a

15 difference signal. The signals fed back through circuits 54, 56 and 76 provide automatic compensation so the circuit of Figure 2 automatically provides the amount of power needed by motor 23a. The speed of engine 12 is controlled so alternator 15 provides the

20 needed power to dc power bus 22 and bridge 24a couples the power to motor 23a. Circuit 75 produces a negative input to adder A6 when the engine speed drops below the desired speed. The difference signal from adder A6 is added to the vehicle speed signal from

25 terminal T2 in an adder A7. The output signal from adder A7 and a steer input signal from control P2 provides a right speed command signal to a circuit 76 for operating a motor to propel track 50 on the right side of a vehicle. The signal from adder A7 and the

30 signal from control P2 cause an adder A19 to produce a left speed command signal to a circuit (not shown) for operating a motor on the left side of a vehicle. A circuit (not shown) for operating the left track motor 23b (Fig. 1) is similar to the circuit of Figure 2 for

35 operating the right motor 23a.

A motor rotor Ro for the right motor (Fig. 2) rotates track sprocket 49 and gear 48 of speed sensor 45. The speed signal from speed sensor 45 is converted to an actual-track-speed signal by a
5 frequency-to-voltage converter 80 and applied to an adder A9 which subtracts the track speed signal from the right speed command signal. A clamp 81 limits the amount of signal applied to an adder A10 to limit the acceleration of motor rotor Ro. When the signal from
10 adder A9 has a positive value a voltage from a voltage-to-frequency converter 82 has an output frequency higher than the rotational velocity of rotor Ro, so power bridge 24a provides a three phase rotating field voltage to motor stators StA, StB, StC
15 which results in a positive slip causing rotor speed to increase. when the signal from adder A9 has a negative value, converter 82 provides an output frequency lower than the rotational velocity of rotor Ro and causes a braking action on the rotor.
20   The track speed signal from converter 80 (Fig. 2) and the signal from adder A9 are applied to an adder A11 which develops a difference signal. An ammeter 86 measures the electrical current to one leg of the stator windings StA – StC and a
25 current-to-voltage converter 87 provide a stator voltage signal to an adder A12. The stator voltage signal is subtracted from the difference signal at adder A12 and applied to a pulse width modulator (PWM) 88. PWM 88 controls the amount of electrical current
30 which power bridge 24a applies to stators StA, StB, StC. The current for bridge 24a is generated by alternator 15 and converted to dc by rectifier 21 which has its output connected to bus 22. Thus, PWM 88 controls the width of electrical current pulses
35 applied to the stators by power bridge 24a, and

converter 82 controls the frequency of these current pulses. Details of these current pulses are shown in waveforms K, M, O of Figure 7. The width of the current pulses determine the power developed by motor 524a, and the frequency of the pulses determine motor speed.

The amplitude of the dc voltage on bus 22 is determined by the speed of engine 12 (Fig. 2) and alternator 15 and by the amount of electrical current
10 applied to an alternator field 92 by a control circuit 93. The vehicle speed signal on input terminal T2 is amplified by a circuit 94 and applied to an adder A13 which adds the amplified speed signal to a fixed voltage to obtain a desired bus voltage signal. The
15 actual bus voltage from bus 22 is subtracted from the desired bus voltage by an adder A14 and applied to a pulse width modulator (PWM) 95. PWM 95 develops pulses which are proportional to the input voltage, with each volt of input providing a pulse width equal
20 to five percent of the time duration. That is, one volt produces a five percent pulse width signal, two volts produce a ten percent pulse width signal, etc. Pulses from PWM 95 cause a transistor Q2 to be conductive so an electrical current flows from bus 22
25 through transistor Q2 and alternator field 92 causing alternator 15 to provide an output to rectifier 21 which raises the bus voltage. when the bus voltage is higher than the desired bus voltage signal to PWM 95, Q2 is rendered nonconductive and the alternator field
30 current drops to zero. A 150 volt input to a terminal T4 causes adder A13 to provide a minimum of 150 volts to adder A14. A dc voltage applied to a terminal T6 provides a voltage to alternator field 92 during start-up periods when the bus voltage is very low.
35   Braking circuit 28 (Fig. 2) controls the

input voltage to a transistor Q1 to limit the upper voltage value on bus 22 and provide electric braking of a vehicle. A minimum of 150 volts from adder A13 plus 25 volts from an input terminal T5 cause an adder
5 A15 to develop a minimum of 175 volts. The output of adder A15 is subtracted from the voltage on bus 22 by an adder A16 and the difference is coupled to a pulse width modulator (PWM) 96. PWM 96 operates similarly to PWM 95 and provides a five percent pulse width
10 output for each volt of input. The pulses from PWM 96 render a transistor Q1 conductive and cause an electrical current to flow from bus 22 through transistor Q1 and resistor 29 to lower the bus voltage. During vehicle braking rotor Ro rotates
15 faster than the field applied to the stators causing the stators to provide power to bus 22 through power bridge 24a thus raising the voltage on bus 22. When the voltage on bus 22 reaches a voltage 20 volts above the voltage from adder A16, PWM 96 supplies a
20 continuous voltage which keeps transistor Q1 turned on thereby connecting resistor 29 to bus 22. The electric track motors 23a, 23b (Figs. 1, 2) generate power which is dissipated in load resistor 29 to provide dynamic braking.

25   Details of a circuit corresponding to the block diagram of Figure 2 are disclosed in Figures 4A, 4B, 5A, 5B, 6A, 6B and 7. Figures 3A and 3B are drawn so that when they are placed side-by-side the leads from the right side of Figure 3A extend to the leads
30 from the left side of Figure 3B to form a control circuit for the right track motor. Figures 4A, 4B are also drawn so leads extend from the right side of Figure 4A to the left side of Figure 4B when they are placed side-by-side. Figures 5A, 5B are similarly
35 drawn. Leads from other portions of these drawings

have identifying letters which indicate where these
leads are connected on other drawings. A voltage on
terminal T2 (Figs. 2, 5A) is proportional to the speed
of a vehicle (not shown) which is controlled by the
5 electronic circuit represented by Figure 2. The
voltage from terminal T2 plus a 4 volt drop across a
zener diode Z1 (Fig. 5A) is applied to both ends of
speed control P1, causing a speed command signal from
P1 to change as vehicle speed changes. Amplifier A2
10 compares the speed command signal from P1 with the
actual vehicle speed signal on terminal T2 and
amplifies the difference. When the output of A2 has a
positive value the voltage from A2 raises the voltage
at a junction point 102. Amplifier A3 provides an
15 engine speed signal equal to an idle speed plus a
constant K times the vehicle speed signal from
terminal T2. An actual commanded engine speed signal
at junction point 102 is the larger of the two
signals. Engine speed circuit 57 (Fig. 5A) comprises
20 a frequency-to-voltage converter 58 which generates a
voltage proportional to engine speed. Amplifier A4 is
an inverting amplifier that produces a negative output
proportional to the difference between the commanded
engine speed and the actual engine speed. Amplifier
25 63 produces an output that is proportional to throttle
position. A capacitor C10 couples a signal
representing the rate of change of the opening of
throttle 62 (Fig. 2), to a resistor R10. Resistors
R10 and R11 form a summing junction at the input of
30 amplifier A5. Amplifier A5 (Fig. 5B) amplifies the
sum of the negative engine speed error and the rate of
change of the throttle opening and drives a pulse
width modulator amplifier 69. Amplifier 69 includes a
PWM chip 101, and an N channel mosfet Q3 which drives
35 servo motor 70 (Fig. 2) to position motor throttle

62. The pulse width from PWM 101 is 100% when the input voltage from a resistor R13 is below -.6 volts, and the pulse width is 0% when the input voltage is above +4 volts. When the input voltage is between -.6

5 and +4 the output varies in a linear manner between 100% and 0% pulse width.

Thus, the engine speed is set by the combination of vehicle speed error, which is the difference between the commanded vehicle speed and the

10 actual vehicle speed. When the difference is positive, the engine speed is raised linearly from 2000 RPM to 5000 RPM. Throttle position is capacitively coupled to a summing junction to limit the rate of opening the throttle when a positive

15 engine speed error occurs. This limiting of the rate of throttle opening allows the engine speed servo to operate at a much higher gain than without it. PWM 69 provides 100% pulse width for engine speed errors above 150 RPM.

20 The vehicle speed error from amplifier A2 (Fig. 5A) also provides an input signal to the track servo motors to control track speeds. The vehicle speed signal from terminal T2 and the vehicle speed error signal from amplifier A2 are summed at the input

25 of an amplifier 100 (Fig. 5B) which provides a signal to amplifier A7 (Fig. 3A). The amplitude of the vehicle speed error signal from amplifier A2 (Fig. 5A) is limited by a pair of zener diodes 106, 107 to a value of 12 volts at the cathode of diode 106 when the

30 speed error is 150 RPM or less. When the engine speed error is 900 RPM, the voltage at the cathode of diode 106 is reduced to a value of zero. Thus diodes 106, 107 limit the amount of power applied to the track motors 23a, 23b (Fig. 1) by reducing the vehicle speed

35 error signal when the engine speed is 150 RPM or lower

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than the commanded engine speed.

The output of amplifier 100 (Fig. 5B) is amplified by an amplifier 108 and summed with a steer signal input at adder A8 (Fig. 3A) for the right track
5 servo motor 23a (Fig. 1). The steer signal is inverted by an amplifier 109 (Fig. 3A) and summed with the output of amplifier 108 by an adder A9 (Fig. 4A). The combination of an amplifier 112, a diode 113 and a resistor 114 (Fig. 3A) form the adder A8 having an
10 output signal equal to the positive value of the input signal and having a zero value of output signal when the input signal has a negative value. The voltage at the cathode of diode 113 is the commanded motor speed for the right track motor. The frequency-to-
15 voltage converter 80 (Fig. 4B) produces a voltage at a set of junctions 118, 118a with the voltage proportional to right motor speed. Speed sensor 45 (Figs. 2, 3A) develops a series of pulses used by converter 80 to develop the output voltage. Converter
20 80 includes a frequency-to-voltage chip 119 and an amplifier 120. One frequency-to-voltage chip 119 which can be used is the Model AD650 made by Intel Corporation, Santa Clara, Corporation. Amplifier 76 (Fig. 3A) amplifies the difference between the
25 commanded motor speed and the actual right motor speed and sums the amplified difference with the actual right motor speed.

$$\text{The output of amplifier } 76 = (V_C - V_S)\ \frac{R53}{R52} + V_S,$$

30 where V_C is the commanded motor speed voltage; V_S is the actual motor speed voltage, and R52 and R53 are the values of resistors R52 and R53. A clamping circuit 81 (Fig. 3A) comprising a pair of amplifiers

123, 124 limit the value of voltage at a junction 125 as a function of motor speed.

The upper limit of positive voltage at junction 125 is limited to a value of

5

$$V_S \left(\frac{R73}{(R73 + R72)} \right) + .6 \text{ volts.}$$

For negative voltages the value is limited to

$$V_S \left(\frac{R57}{(R56 + R57)} \right) - .6 \text{ V}$$

10 where R72, R73, R56, R57 are the value of these resistors at circuit 81.

A voltage-to-frequency converter 82 (Fig. 3B) has an input voltage applied to a resistor R75. The input voltage at R57 is

15

$$(V125 - V_S) \times \frac{R74}{R74 + R55} + V_S.$$

The voltage at junction 125 is

$$(\text{output of } 76 - V_S) \times \frac{R55 + R74}{R55 + R74 + R54} + V_S$$

20 and the voltage is clamped to the values listed above. Substituting the output of circuit 76

$$V125 = \left[(V_C - V_S) \left(\frac{R53}{R52} + V_S \right) - V_S \right] \frac{R55 + R74}{R55 + R74 + R54} + V_S$$

$$= (V_C - V_S) \frac{R53}{R52} \times \frac{R55 + R74}{R55 + R74 + R54} + V_S$$

25

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$$VR75 = \left[(V_C - V_S) \frac{R53}{R52} \times \frac{R55 + R74}{R55 + R74 + R54} + V_S - V_S\right]$$

$$\frac{R74}{R74 + R55} + V_S$$

$$^5 VR75 = (V_C - V_S) \frac{R53}{R52} \times \frac{R55 + R75}{R55 + R74 + R54} \times \frac{R74}{R74 + R55} + V_S.$$

When the commanded motor speed V_C and the
actual motor speed V_S are equal, $VR75 = V_S$ and
voltage-to-frequency converter 82 (Fig. 3B) produces
10 an output frequency equal to the input frequency at
frequency-to-voltage converter 119. The output of
converter 82 provides a clock to a programmable logic
array U12. Programmable logic array U12 provides
output signals to a plurality of N channel mosfets Q5
15 - Q10 which generate three-phase waveforms to control
electrical current from power bridge 24a (Figs. 1, 2,
6) to windings StA, StB, StC of right track motor
23a. One programmable logic array U12 which can be
used in the present circuit is the Model P22V10 made
20 by Intel Corporation, Santa Clara, California.

        The three-phase waveforms cause the induction
track motor to rotate clockwise or counterclockwise as
commanded on input pin #2 by a debouncer circuit 129
(Fig. 3B). Debouncer circuit 129 receives forward and
25 reverse command signals from a forward/reverse switch
130 (Fig. 3A) and receives motor speed signals from
speed sensor 45. Actual motor direction from speed
sensor 45 is transmitted to pin 3 of array U12 by
debouncer circuit 129. Programmable logic array U12
30 steps through one electrical cycle for every 24 clock
pulses on input pin #1. The motor speed feedback gear
48 (Fig. 2) has 48 teeth and the motor is a 4-pole
motor, so two electrical cycles are required for each

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revolution. When $V_C - V_S$ is equal to zero, the output motor frequency is equal to the motor synchronous frequency. when V_C is greater than V_S, the output motor frequency is raised linearly above the
5 synchronous frequency until it is clamped by amplifier 123 and diode CR10 (Fig. 3A) in clamping circuit 81. when V_C is less than the synchronous frequency, the output frequency is lowered linearly below the synchronous frequency until it is clamped by amplifier
10 124 and diode CR9.

The output of the speed error amplifier 76 (Fig. 3A) and motor speed V_S are used to command a motor current at the cathodes of diodes CR14 and CR15. Amplifier U16B produces a voltage at the
15 cathode of diode CR14 having a value of:

$$V_{C}R14 = (V_C - V_S) \frac{R53}{R52} \times \left(1 + \frac{R94}{R111}\right) + V_S.$$

Diode CR14 limits the output to positive values only.

Amplifier U16C produces at voltage at the
20 cathode of diode CR15 having a value of:

$$V_{C}R14 = V_S + (V_S - V_C) \frac{R53}{R52} \times \frac{R113}{R124}$$

Diode CR15 limits the output to positive values only. The voltage at the cathodes of diodes CR14 and CR15 is
25 the commanded motor current. It is summed with motor current feedback at the junction of resistors R95 and R86. Inverting amplifier U16A produces a negative going output voltage which is proportional to the difference between the commanded current and the
30 actual current. The voltage at the output of U16A is:

$$V_C R16 = \frac{R114}{R114 + R115} \times 15 \text{ V} \times \frac{R97}{\frac{R86 \times R95}{R86 + R95}}$$

$$5 \qquad - \left[V_C R14\text{-}CR15 + VU14\text{-}14 \right] \frac{R97}{\frac{R86 \times R95}{R86 + R95}}$$

$$V_C R16 = \frac{R97}{\frac{R86 \times R95}{R86 + R95}} \times \left[\frac{R114}{R114 + R115} \times 15 \text{ V} - (V_C R14\text{-}CR15 + \right.$$

$$10 \qquad \left. VU14\text{-}14) \right]$$

The output voltage of amplifier U16A is initially set at +4 volts by

$$15 \quad \frac{R114}{R114 + R115} \times 15 \text{ V} \times \frac{R97}{\frac{R86 \times R95}{R86 + R95}}$$

swings down to a -.6 and is clamped by diode CR16. Pulse width modulator 88 (Fig. 3B) includes circuit U17 which produces a 100% duty cycle with an input of -.6v from amplifier U16A and produces a 0% duty cycle with 20 an input of 4 volts and above. Resistor R126 and capacitor C50 set the output pulse frequency of U17 at 3KHz which is coupled to the programmable logic array U12.

Programmable logic array (PLA) U12 (Fig. 3B) 25 provides a plurality of pulse modulated signals to a plurality of mosfets Q5, Q7, Q9 which provide voltage waveforms K, M, O (Fig. 7) respectively to terminals K, M, O (Fig. 6) of right track bridge 24a. Signals from U12 provides a plurality of motor frequency pulses to a 30 plurality of mosfets Q6, Q8, Q10 which provide voltage waveforms L, N, P (Fig. 7) to terminals L, N. P of right track bridge 24a (Fig. 6). Terminals AG, AH, AI

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(Figs. 2, 6) are connected to stator windings StA, StB, StC (Fig. 2) of right track motor 23a (Fig. 1). Terminals AG', AH' and AI' (Fig. 6) are for connection to motor 23b (Fig. 1) in the same manner that terminals

5 AG, AH, AI are connected to motor 23a (Fig. 2). A plurality of terminals AJ - EJ and AL - EL are connected to a plurality of current sensors 86a, 86b, 86c (Figs. 5A, 6) which provide current values to an amplifier U14A in current-to-voltage converter 87.

10 Amplifier U14A sums and amplifies the currents and couples the sum to inverting amplifier U14D (Fig. 3A), and to a power bridge shutoff circuit 132 (Fig. 3B).

        Shutoff circuit 132 includes a timer U4 and a transistor Q17 (Fig. 3B). When the voltage at the base

15 of transistor Q17 exceeds .6 volts transistor Q17 is rendered conductive and triggers timer U4. The output voltage on pin 3 of timer U4 stays high as long as Q17 conducts and for a subsequent period of time which is determined by the values of resistor R22 and capacitor

20 C12. Output pin 3 of timer U4 is connected to pin 5 of PLA U12 of Figure 3B and to pin 5 of a PLA U12A of Figure 4B. The voltages on output leads 10 - 11, 13 - 16 of PLA U12, U12A are turned off when the current limit input to U12, 12A is high.

25   Amplifier U19A (Fig. 3A) is a level detector with positive feedback. When V_S from amplifier 120 is low the output of U19A is high and the noninverting input is biased at a value of:

$$30 \quad \frac{R169}{R169 + (R168 \ \& \ R143 \ in \ parallel)} \times 15v$$

        When V_S rises above this bias value the output goes low and the noninverting input is biased at a value of:

$$\frac{R169}{R169 + (R168 \text{ \& } R143 \text{ in parallel})} \times \left[\frac{R143}{R168 + R143} \times 30 - 15v \right]$$

When V_S drops below this value the output
5 goes high.

         The output of amplifier U19A is connected to
PLA U12 through resistors R144, R145 which converts
the 15 volt signal to a 5 volt signal. PLA U12 is
programmed to inhibit the drive motor from changing
10 directions when the voltage on input pin 4 is low.

         Amplifier U19B (Fig. 3A) is a voltage
follower that sums the right motor speed (Fig. 6A) and
the left motor speed (Fig. 4A). The output of U19B
(Fig. 3A) is amplified by amplifier A13 (Fig. 5A) and
15 the output of A13 is summed with a reference voltage
created by resistors R181 and R131. The voltage at
junction point 131 is the commanded dc bus voltage.
Amplifier A15 produces an output voltage proportional
to engine speed and clamps the commanded dc bus
20 voltage through diode CR101. Commanded dc bus voltage
is controlled as a function of the sum of the motor
speeds and is limited by engine speed.

         The actual bus voltage on input lead J (Figs.
3B, 5B) is coupled through resistor R165 to inverting
25 amplifier A14 (Fig. 5A). When the actual bus voltage
is less than the commanded bus voltage at junction
point 131 the output voltage of A14 decreases
proportionally. When the output of A14 is -.6 volts
PWM amplifier provides 100% pulse width to the
30 alternator field 92 (Fig. 2) on line X (Figs. 2, 5B).
When the output voltage from A14 is 4 volts the pulse
width to alternator field 92 is zero. When the bus
voltage to non-inverting amplifier A16 rises above the

commanded voltage at junction point 131 the output of
A16 goes low. When the output of A16 reaches -.6 volts
PWM, 96 provides full pulse width to input lead W
(Figs. 5B, 6) of braking circuit 28 so a braking
5 current flows through resistor 29 (Figs. 2, 6) to
provide brake of a vehicle.

The circuit of Figures 3A, 3B and portions of
Figures 5A, 5B, 6 control operation of right track
motor 23a (Fig. 1). In a similar manner, the circuits
10 of Figures 4A, 4B and portions of 5A, 5B, 6 control the
operation of left track motor 23b (Fig. 1). The
circuits of Figures 4A, 4B which function similarly to
the circuits of Figures 3A, 3B have been given similar
part numbers. For example, PWM 88 of Figure 3B and PWM
15 88a of Figure 4B operate in a similar manner to control
power to motors 23a and 23b respectively.

Power bridge circuits 24a, 24b (Figs. 1, 6)
provide pulses of current which cause motors 23a, 23b
to develop a very high torque at low engine speeds
20 while using a small amount of electrical power from
rectifier 21. A portion of Figure 6 has been redrawn
as Figure 8 to illustrate how this is done using the
signals K - P from Figure 3B applied to the
corresponding signal input terminals of Figures 6 and
25 8. The shapes of these signal waveforms K - P are
illustrated in Figure 7. The same terminal AG is shown
in two locations in Figure 8 in order to simplify the
drawing.

At a time t_1 (Fig. 7) signal K renders
30 transistor 136a (Figs. 6, 8) conductive and signal N
renders transistor 138a conductive. A current IB flows
from common dc bus 22 through transistor 136a, stator
winding StB, transistor 138a and diode 144a to ground.
At time t_2 the inductance of winding StB keeps IB
35 flowing through transistor 138a, and diodes 144a, 143a

with only a small change in current amplitude as shown in waveform Ia of Figure 7. At time t_4 current IB again flows in the same current path as at time t_1. Current IB provides power to operate motor 23a.

5   At time t_7 (Fig. 7) voltage waveform N cuts off current through transistor 138a, but voltage waveform P holds transistor 138b conductive and voltage waveform M renders transistor 136b conductive. A current IC flows from dc bus 22 through transistor 136b, stator winding StC, transistor 138b and diode 144b to ground. The inductance of winding StB also causes current to flow from bus 22 through transistor 136a, winding StB and diode 142a to bus 22.

       At time t_{13} voltage waveform O (Fig. 7) renders transistor 136c (Fig. 8) conductive and voltage waveform L keeps transistor 138c conductive. A current IA flows from bus 22 through transistor 136c, winding StA, transistor 138c and diode 144c to ground. At time t_{14} the inductance of winding StA keeps IA flowing through transistor 138c, diode 144c and through diode 143c with only a small change in current amplitude. The width of the pulses of waveforms K, M and O is very short compared to the time between pulses so the average value of current from bus 22 and capacitor 145 is much lower than the value of the currents IA, IB, IC through stator windings StA, StB, StC. As a result, motors 23a, 23b provide an extremely high torque with a very small amount of electrical power from bus 22. For example, at low motor speeds the average current IB (Fig. 7) can be approximately 1000 amps while bus 22 supplies approximately 10 amp of current. The waveforms K, M, O are not drawn to scale as the pulses are actually very narrow compared to the time between pulses when motors 23a, 23b operate at speeds between 0 and 10 rpm.

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        Although   the   best   mode   contemplated   for
carrying   out   the   present   invention   has   been   herein
shown   and   described,   it   will   be   apparent   that
modification   and   variation   may   be   made   without
5 departing   from   what   is   regarded   to   be   the   subject
matter of the invention.
LBG:smb

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What is claimed is:

1.   An   electrical   propulsion   system   for
controlling motor speed and power over a wide range of
motor speeds, said system comprising:
        an   induction   motor   having   a   rotor   and   a
plurality of stator windings;
        means for developing a signal proportional to
rotor speed;
        means   for   providing   a   desired   rotor   speed
signal;
        means   for   comparing   said   rotor   speed   signal
and   said   desired   speed   signal   and   developing   a
difference signal;
        means   for   using   said   difference   signal   to
provide   pulses   of   current   to   said   stator   windings   to
set a speed of said induction motor to a desired value.

2.   An   electrical   propulsion   system   as
defined   in   claim   1   including   means   for   using   an
inductance of said stator windings to provide   a   stator
current during a time between said pulses of current.

3.   An   electrical   propulsion   system   as
defined in claim 1 including an   engine,   an   alternator
coupled   to   said   engine   and   to   said   induction   motor,
and   means   for   sensing   said   difference   signal   to
control   the   speed   of   said   engine   and to control an
amount of current supplied by said alternator   to   said
motor.

4.   An   electrical   propulsion   system   as
defined in claim 1 including means for   controlling   the
width   of   said   current   pulses to determine the amount
of power developed by said motor.

5.   An   electrical   propulsion   system   as
defined   in   claim   1 including means for controlling the
frequency   of   said   current   pulses   to   determine   the

-22-

speed of said motor.

6. An electrical propulsion system for powering and steering vehicles by providing individual power .to a pair of vehicle drive wheels in response to a speed command signal and a steering command signal, said system comprising:

first and second electric induction motors;

means for coupling said first motor to a first vehicle drive wheel and for coupling said second motor to a second vehicle drive wheel;

means for developing a first drive speed signal by sensing the speed of said first vehicle drive wheel;

means for combining said first drive speed signal with a speed command signal and a steering command signal to develop a first motor control signal;

a dc power bus for providing electrical power to said first and said second motors;

means for using said first motor control signal to couple said first motor to said power bus for controlling the speed of said first motor;

means for developing a second drive speed signal by sensing the speed of said second vehicle drive wheel;

means for combining said second drive speed signal with said speed command signal and said steering command signal to develop a second motor control signal; and

means for using said second motor control signal to couple said second motor to said power bus for controlling the speed of said second motor.

7. An electrical propulsion system as defined in claim 6 including means for coupling power from any one of said first and said second motors to said dc power bus when a speed of said coupled motor

is greater than a speed asked for by a motor control signal.

8. An electrical propulsion system as defined in claim 7 wherein power coupled from one of said motors to said dc power bus provides a braking action on said motor.

9. An electrical propulsion system as defined in claim 6 including means for coupling power from an inside motor to said dc power bus when a vehicle is making a turn, said coupled power providing added power to an outside motor during said turn.

10. An electrical propulsion system for powering and steering vehicles by providing individual power to a left vehicle drive wheel and to a right vehicle drive wheel in response to a speed command signal and a steering command signal, said system comprising:

first and second electric induction motors each having a rotor and a plurality of stator windings;

means for coupling said first motor to a left drive wheel and for coupling said second motor to a right drive wheel;

means for developing a left drive speed signal by sensing the speed of said left drive wheel;

means for combining said left drive speed signal with a speed command signal and a steering command signal to develop a left motor control signal;

a left power bridge for using said left motor control signal to provide a plurality of electrical current pulses to said stator windings of said first motor to operate said first motor;

means for developing a right drive speed signal by sensing the speed of said right drive wheel;

means for combining said right drive speed signal with said speed command signal and said

steering command signal to develop a right motor control signal; and

a right power bridge for using said right motor control signal to provide a plurality of electrical current pulses to said stator windings of said second motor to operate said second motor.

11. An electrical propulsion system as defined in claim 10 including means for using an inductance of said stator windings to provide a stator current during a time between said pulses of electrical current.

12. An electrical propulsion system as defined in claim 10 including a dc power bus connected to provide power to said right and said left power bridges for providing power to said first and said second motors, either of said first and said second motors returning power to said dc power bus when a speed of said motor is greater than a speed asked for by a motor control signal, said returning power providing a braking action on said motor.

13. An electrical propulsion system as defined in claim 10 wherein a frequency of said electrical current pulses to each of said motors determines a speed of a corresponding motor and a width of said electrical current pulses determines an amount of power developed by said corresponding motor.
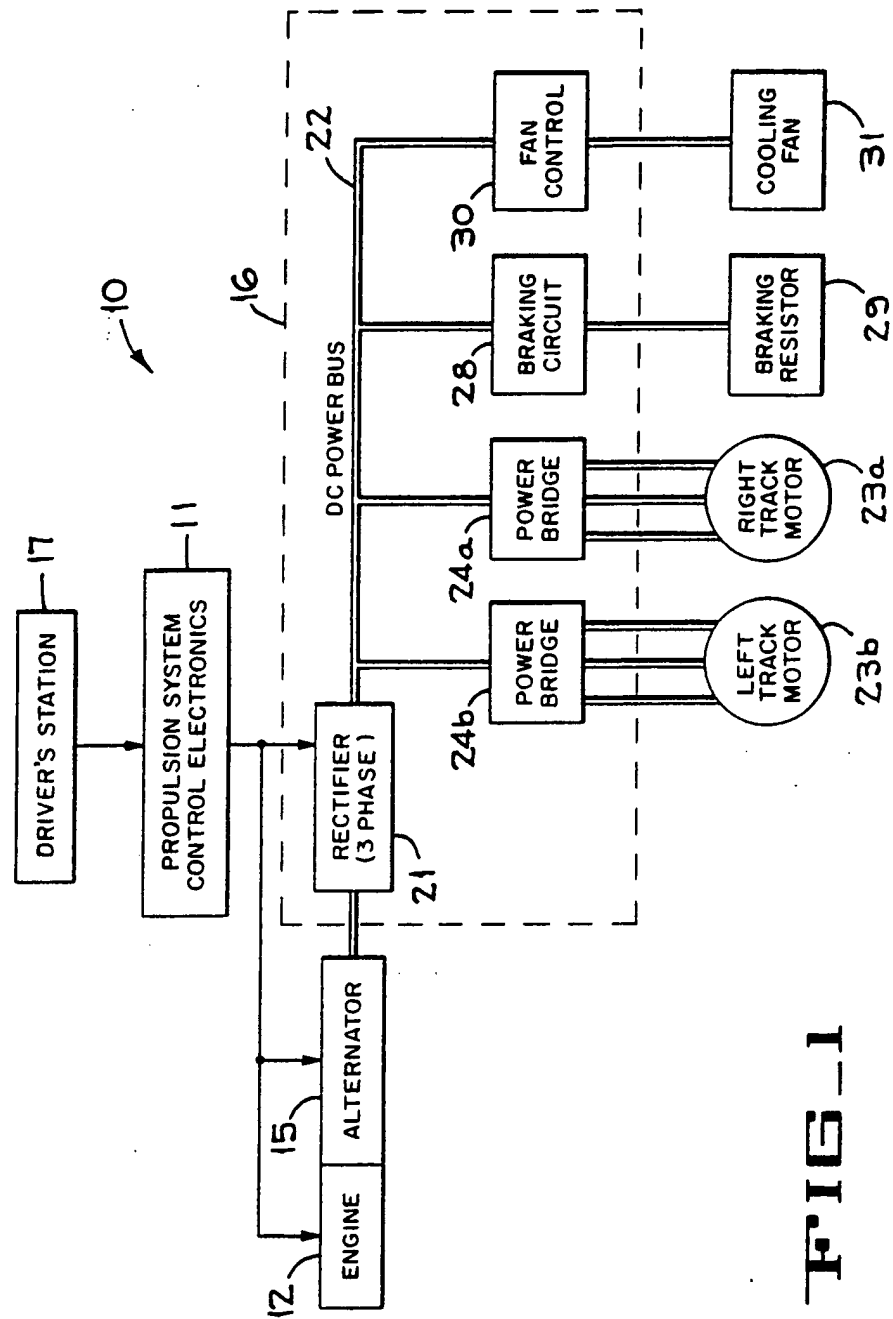
14. an electrical propulsion system as defined in claim 10 wherein steering a vehicle in a relatively tight turn causes a motor connected to a drive wheel on an inside portion of said turn to provide added power to said dc power bus and wherein said added power causes an enhanced operation of a motor connected to a drive wheel on an outside portion of said turn.

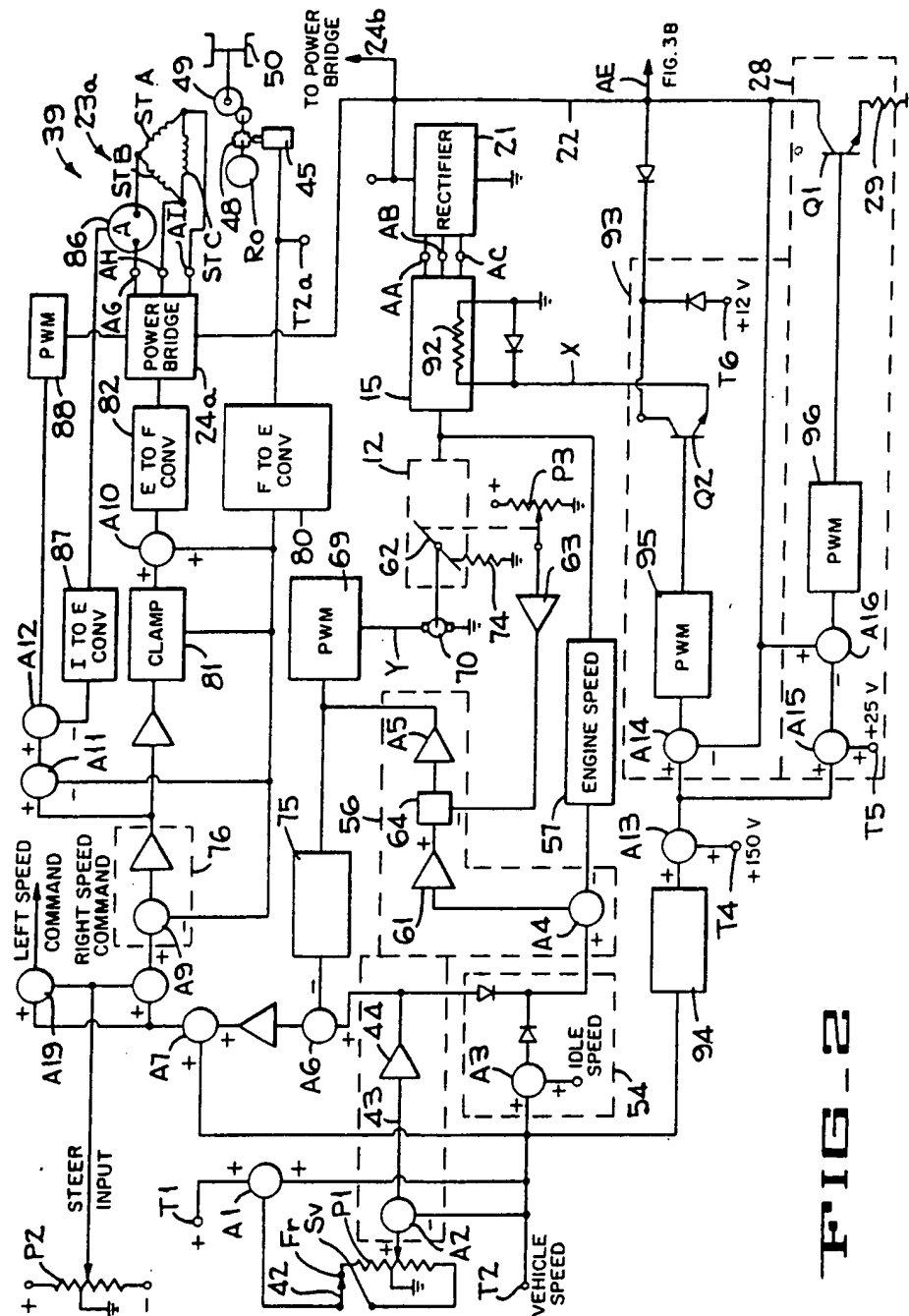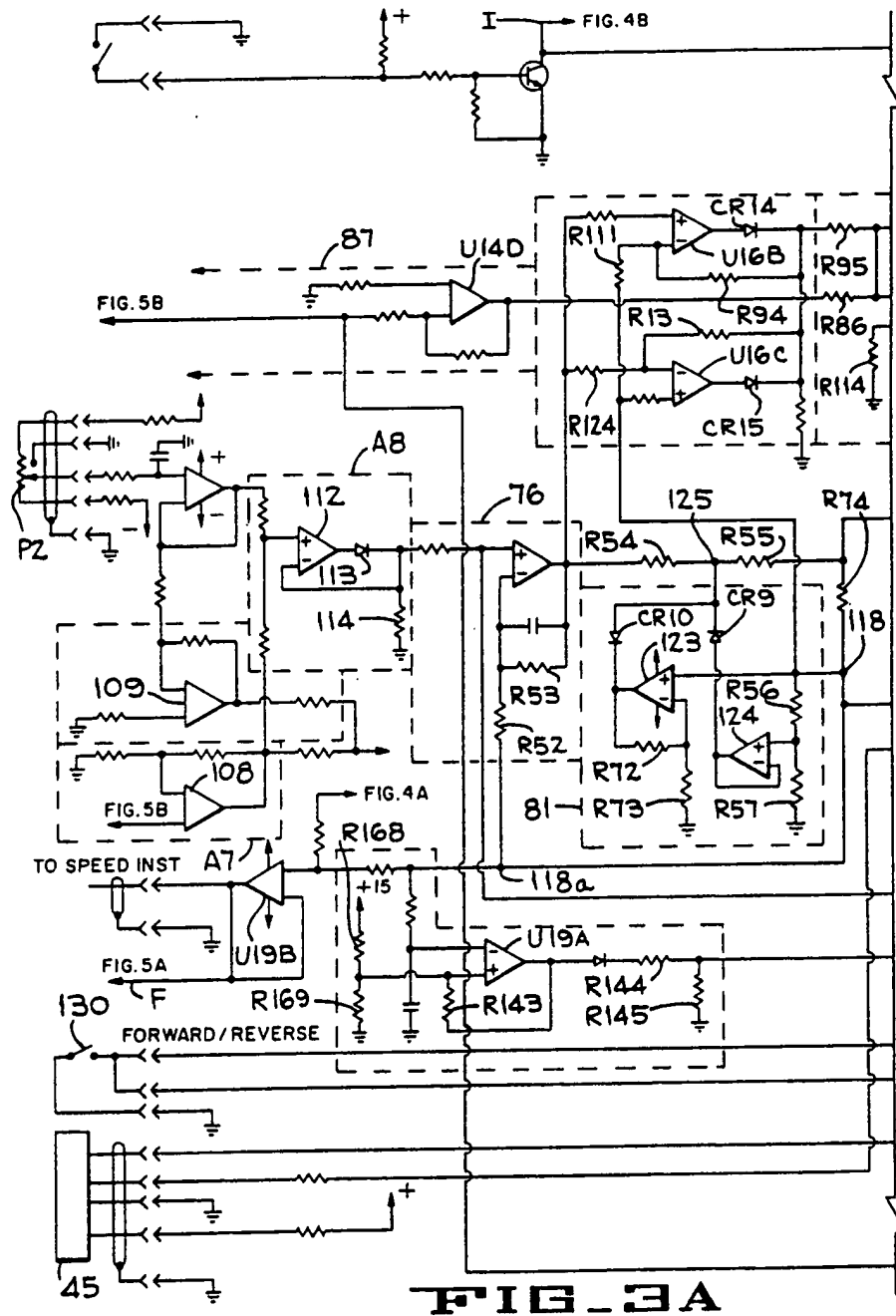15. An electrical propulsion system as

defined   in   claim 10 including an alternator for
providing electrical power to said right and said left
power bridges, an engine coupled to said alternator to
operate said alternator, means for using developing an
actual vehicle speed signal, means for using a speed
command signal and said actual vehicle speed signal to
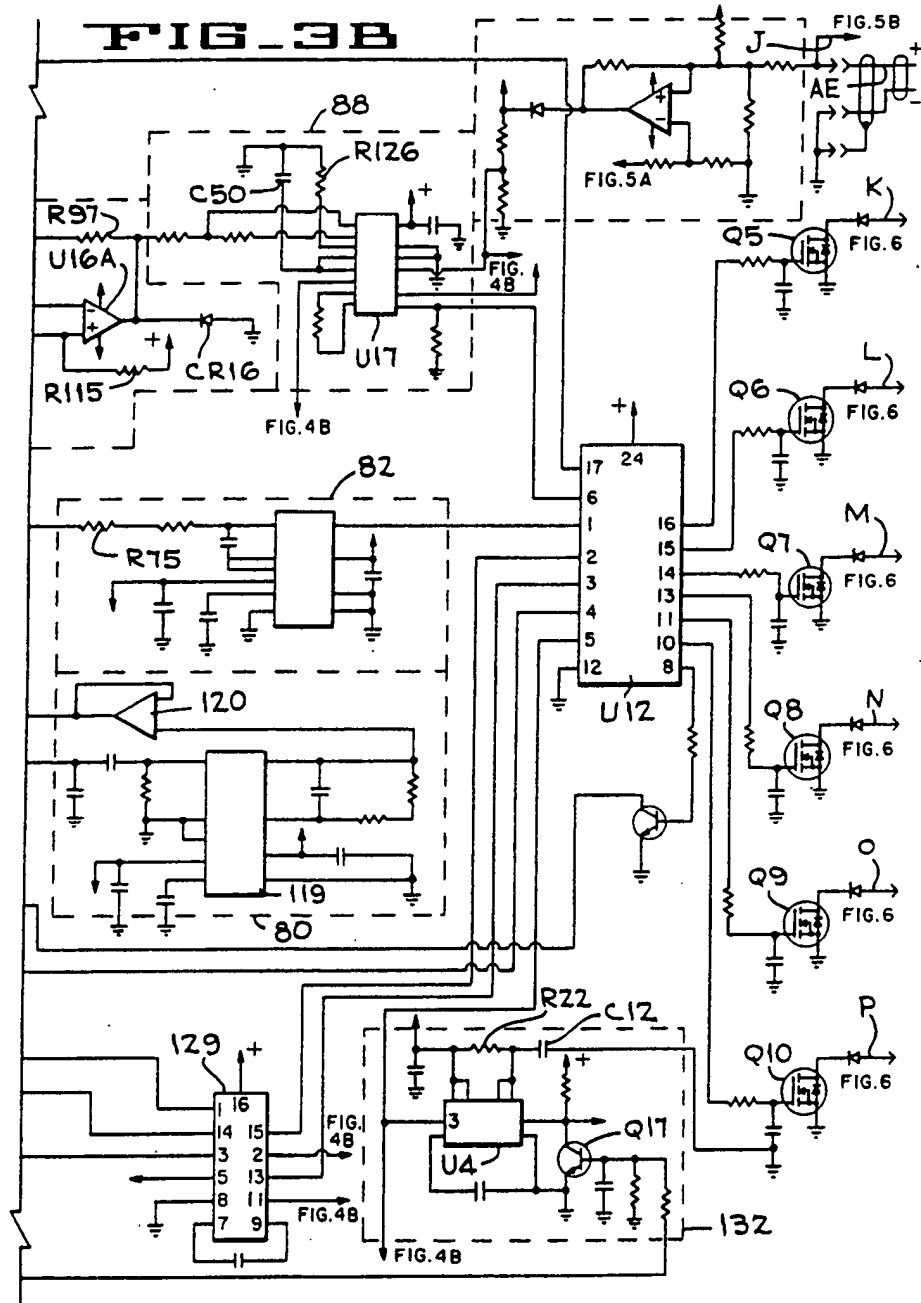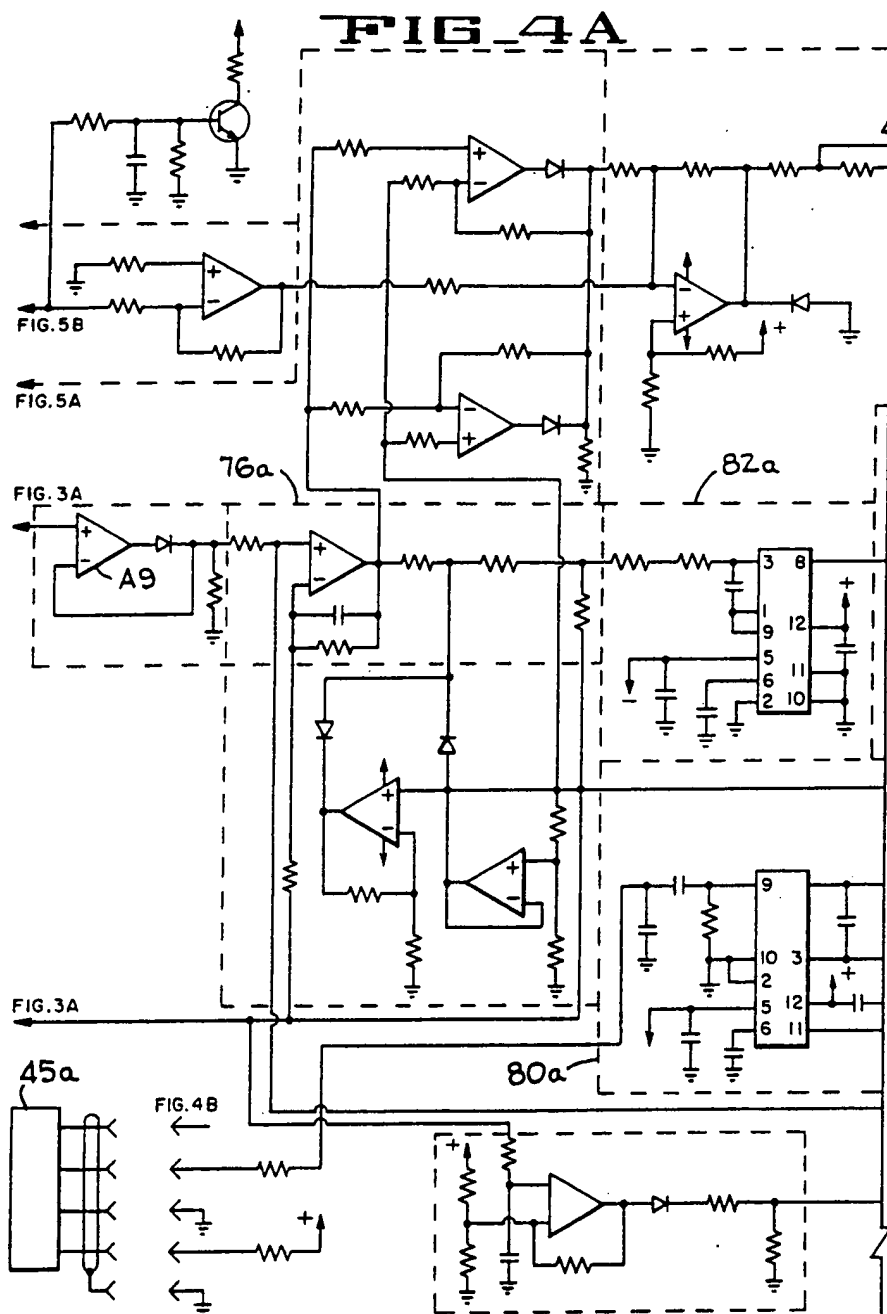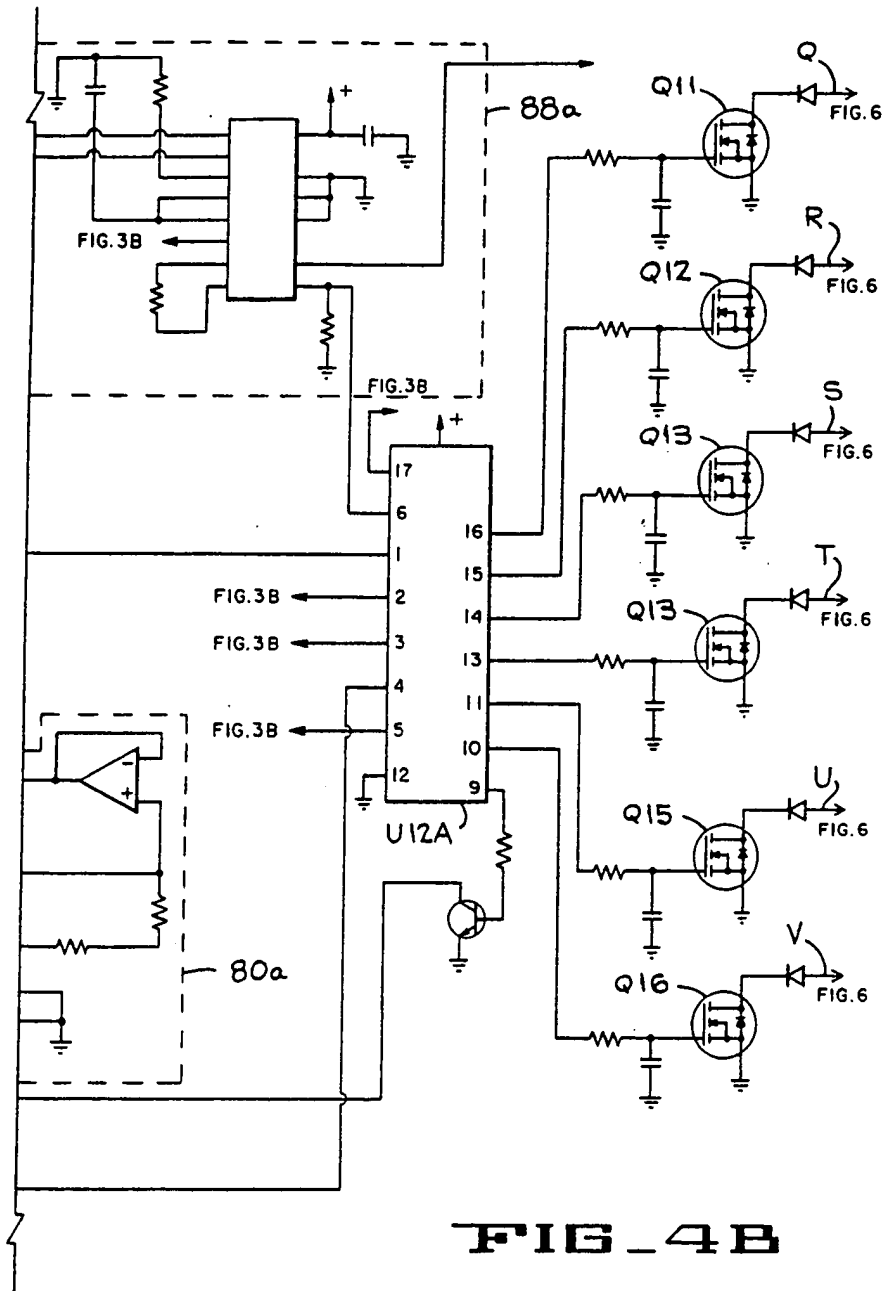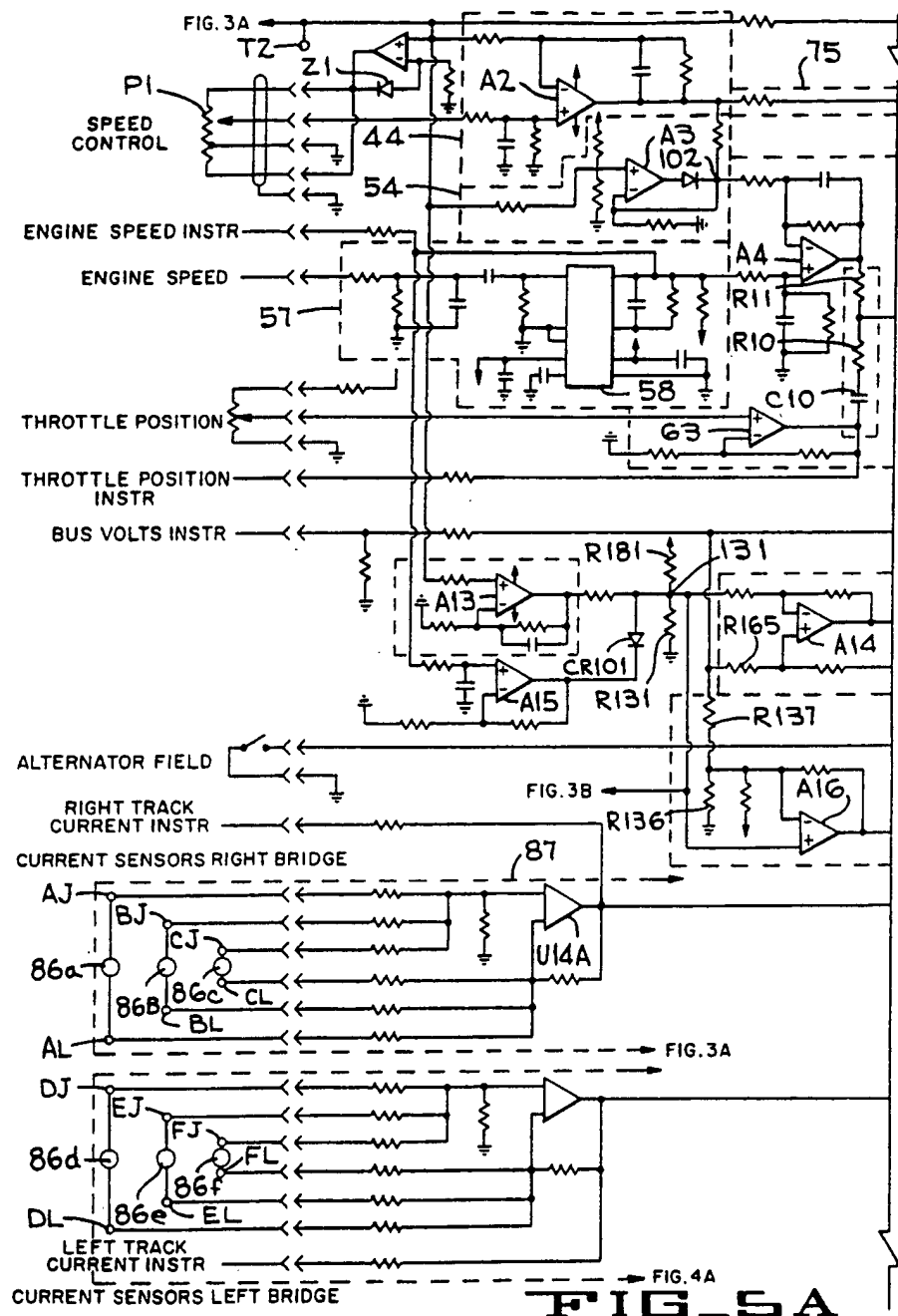develop   a difference speed signal for controlling
engine speed.

FIG_1

FIG_2

FIG_3A

FIG. 3B

FIG. 4A

FIG_4B

FIG. 3A

TZ

Z1

PI

SPEED
CONTROL

A2

44

54

A3
102

ENGINE SPEED INSTR

ENGINE SPEED

57

58

A4

R11

R10

C10

75

THROTTLE POSITION

63

THROTTLE POSITION
INSTR

BUS VOLTS INSTR

R181

A13

CR101

A15   R131

131

R165

A14

R137

ALTERNATOR FIELD

FIG. 3B

A16

R136

RIGHT TRACK
CURRENT INSTR

CURRENT SENSORS RIGHT BRIDGE

87

AJ

BJ

CJ

86a

86B 86c CL

BL

U14A

AL

FIG. 3A

DJ

EJ

FJ

86d

FL

86f

DL   86e   EL

LEFT TRACK
CURRENT INSTR

CURRENT SENSORS LEFT BRIDGE

FIG. 4A

FIG_5A
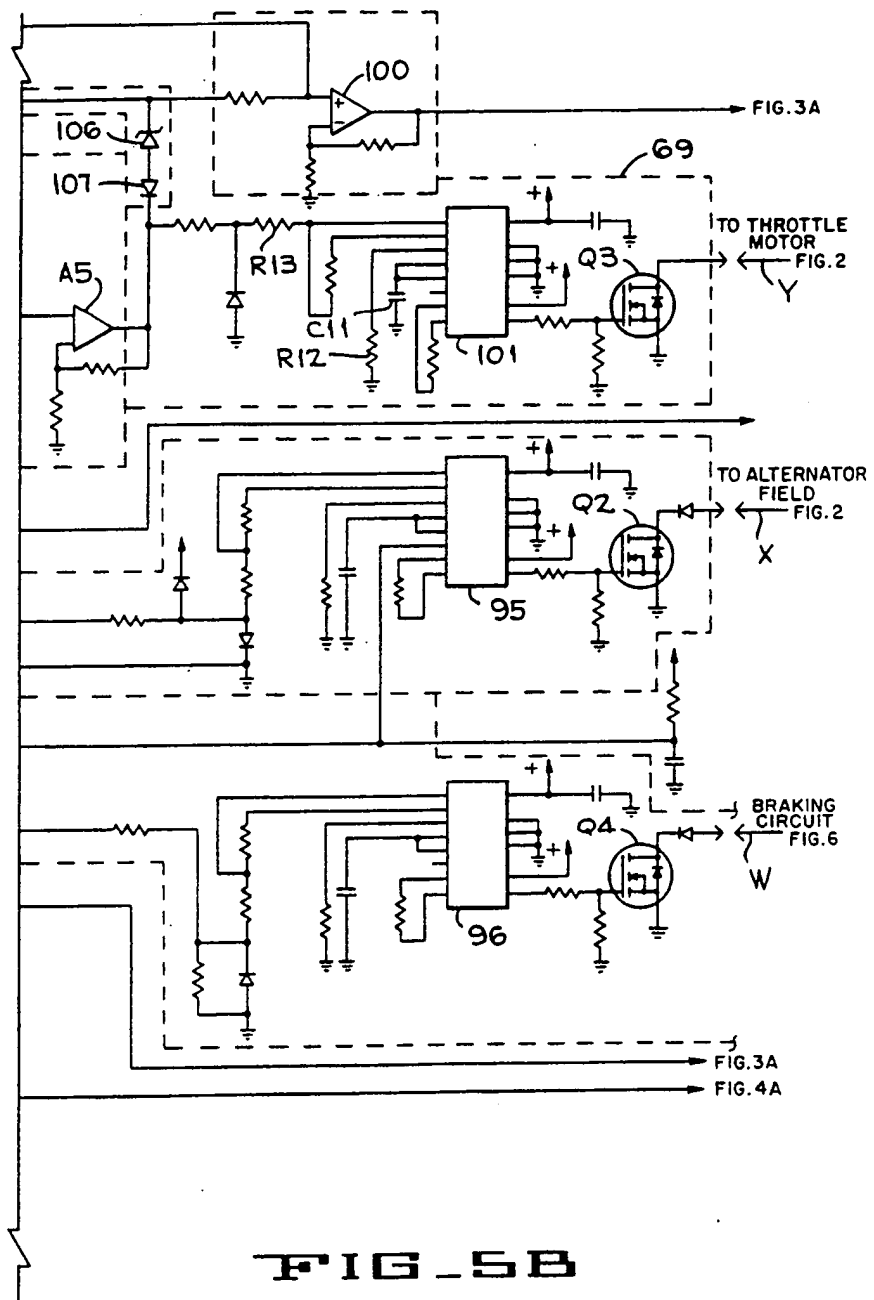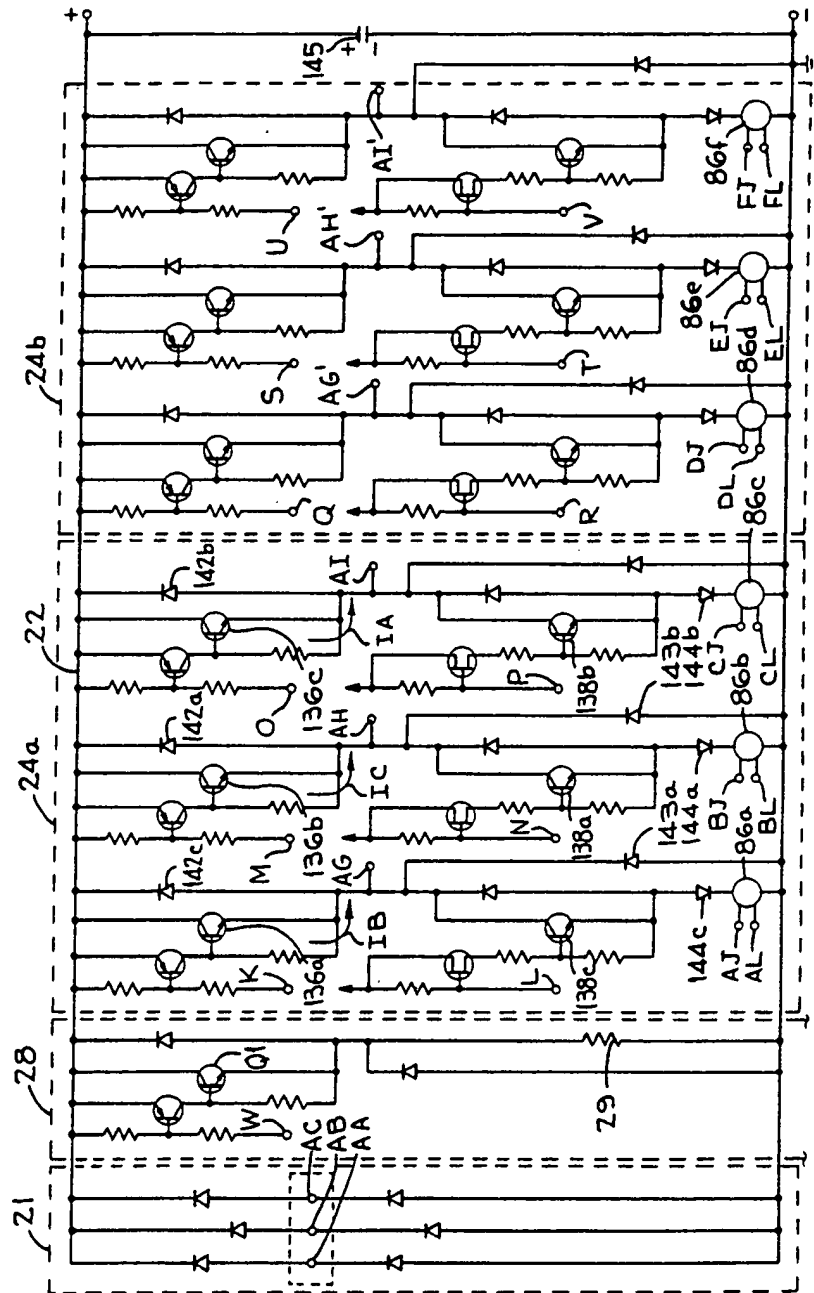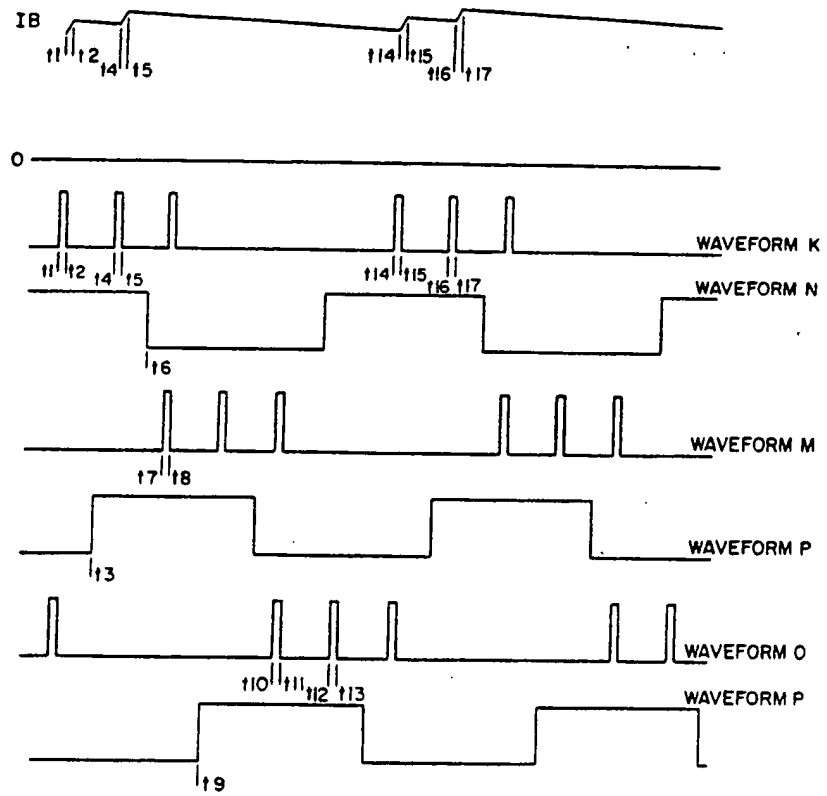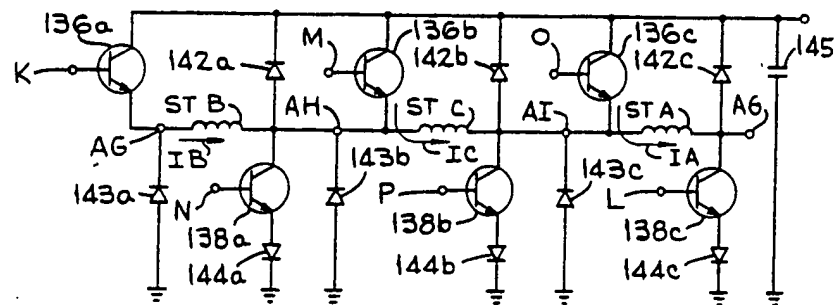
FIG_5B

FIG_6

FIG_7

FIG_8

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/07203

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (5): H02P 7/74 B62D 6/02

U.S.Cl.: 318/60 180-6.5

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷

Classification System	Classification Symbols
U.S.	318/52,56,57,60,63 180/6.48,6.5

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched ⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹

Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US, A, 3,323,032 (AGARWAL ET AL.) 30 May 1967 Note Camparator 48; Figure 12; column 3, lines 62-69.	1-5
X	US, A, 4,292,531 (WILLIAMSON) 29 September 1981 Note entire document.	6
Y	US, A, 3,720,863 (RINGLAND ET AL.) 13 March 1973 Note column 33, lines 6-16; column 35, lines 39-44.	6-15

* Special categories of cited documents: ¹⁰

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
15 January 1992	06 FEB 1992

International Searching Authority	Signature of Authorized Officer
ISA/US	William Shoop, Jr.

Form PCT/ISA/210 (second sheet) (Rev.11-87)